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International Earth Science Constellation Mission Operations Working Group

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TanSat Analysis and Status

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Agenda

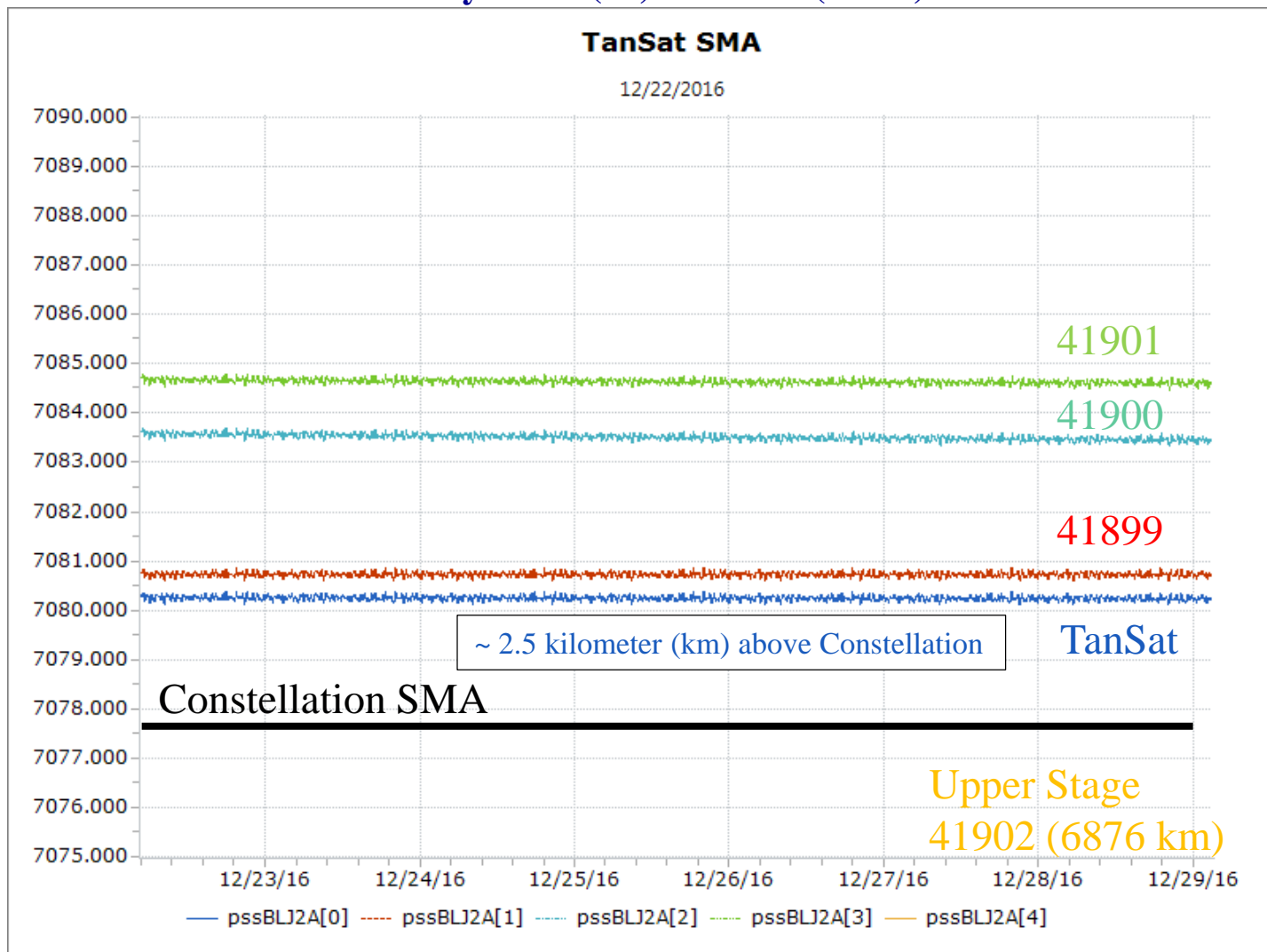
- Recap of Initial Post-Launch Assessment
- Mission Plan Development
- Evolution of Operational Support
- “What If” Constellation Insertion Analysis
- Current Status Package Content
- Latest Status

Post-Launch Summary

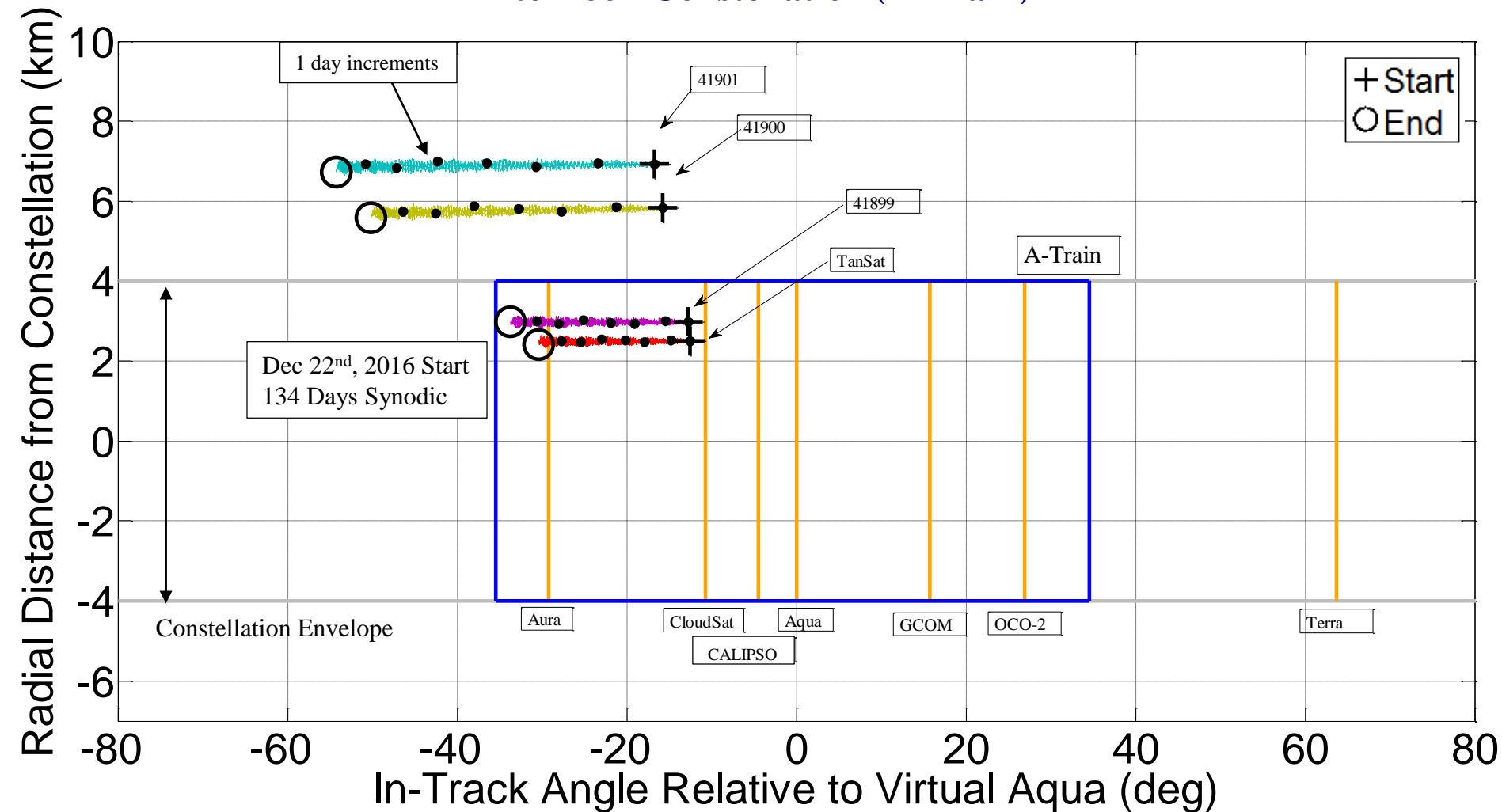
- TanSat launched on Dec 21st, 2016 at 19:22 Coordinated Universal Time (UTC)
- Five objects were initially tracked (four with stable orbits)
 - TanSat (41898)
 - Micro-Nano Satellites (41899, 41900, 41901)
 - Chang Zheng-2d (CZ-2d) Rocket Body Upper Stage (41902), highly eccentric orbit
- Two-Line Element (TLE) sets made available on Constellation Coordination System (CCS)
- First Vector Covariance Message (VCM) file analyzed by Flight Dynamics System (FDS) provided December 22nd, 2016 at 17:16 UTC

Object	Perigee (km)	Apogee (km)
TanSat (41898)	696	721
41899	696	722
41900	695	727
41901	695	730
Upper Stage (41902)	276	732

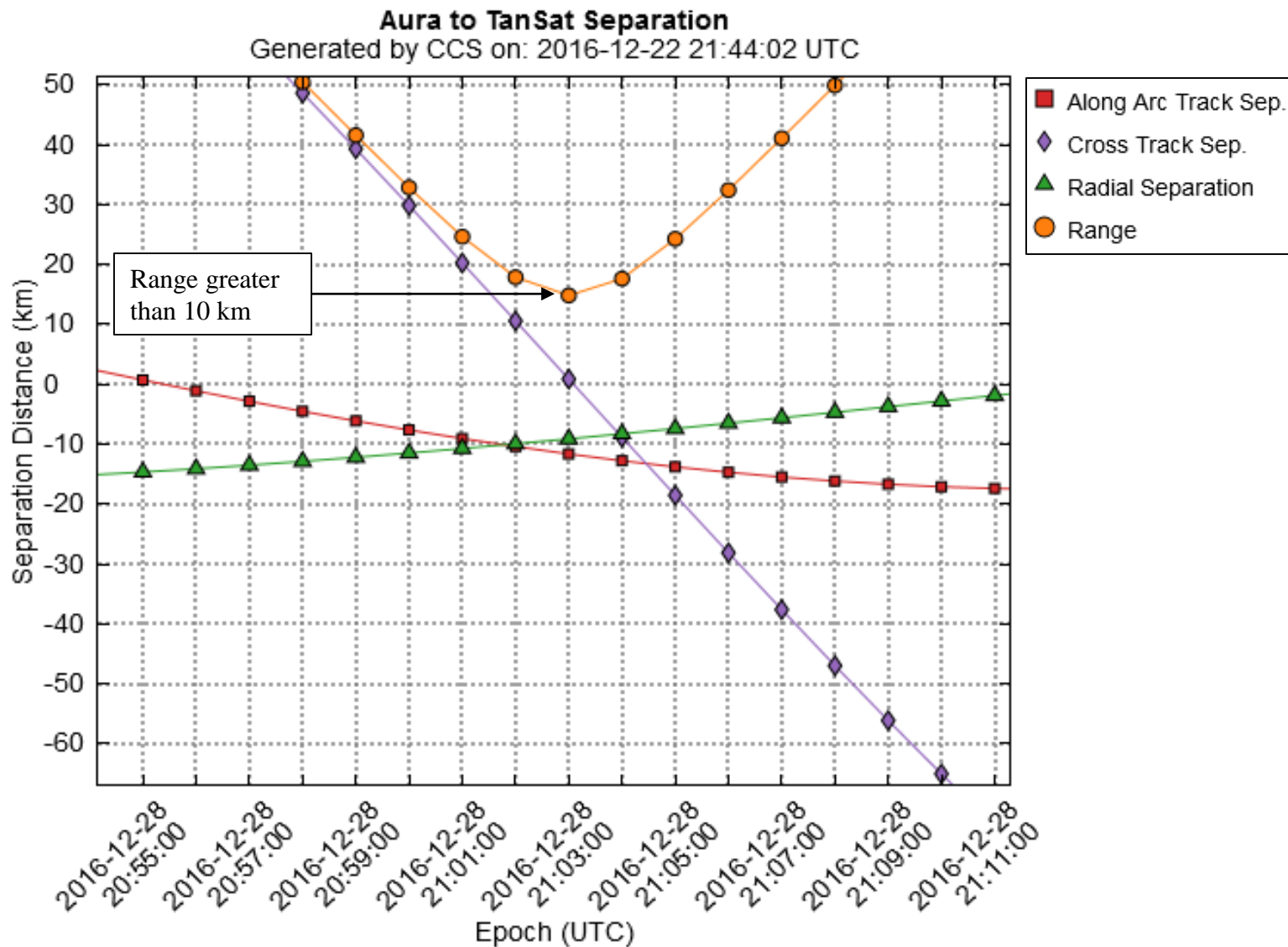
Initial Post-Launch Semi-Major Axis (SMA) Plot using Brouwer-Lyddane (J2) elements (BLJ2)



Initial Post-Launch Phasing Plot with Afternoon Constellation (A-Train)



Post-Launch Aura Crossing



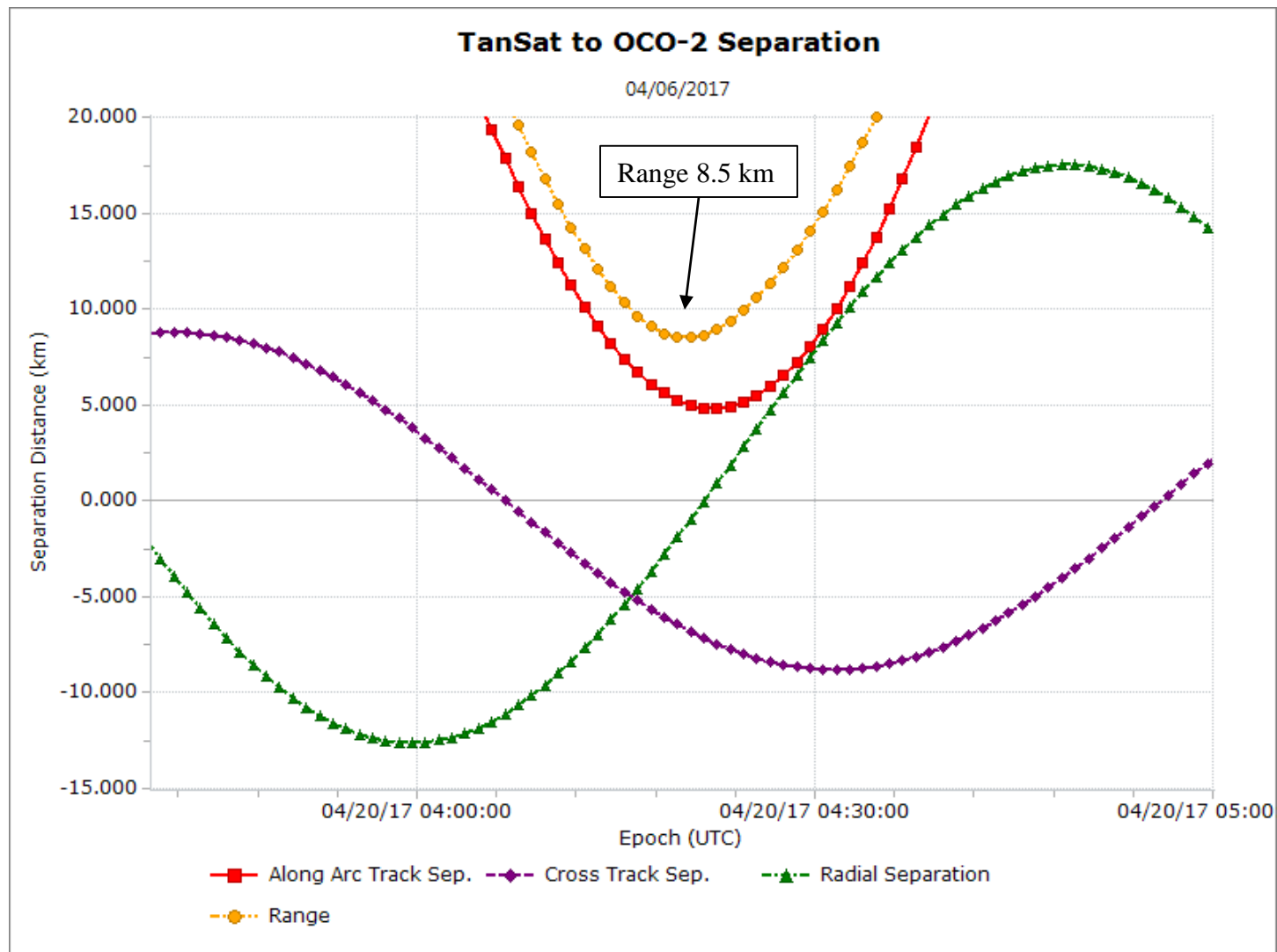
- Using TanSat TLE – `TanSat_tansat_20161222_191509.tle_2016356000000_2017`

- TanSat has since had the following crossings (minimum range dates):
 - Landsat-8 on January 5th, Landsat-7 on March 14th, and Terra on April 5th
 - Orbiting Carbon Observatory -2 (OCO-2) on April 18th and Global Change Observation Mission - Water (GCOM-W1) "SHIZUKU" on April 23rd
 - Aqua on April 29th and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) on May 1st
 - CloudSat on May 3rd
 - Aura on May 14th
- Most crossings had large total miss distances, although some had small miss components (e.g., Radial, Cross-Track)
- Relatively high orbit eccentricity and perigee rotation contributes to the large crossing variations
- Timing of GCOM-W1 crossing was prior to their Inclination Adjust Maneuver (IAM), and the maneuver was deemed safe to perform
- FDS team generated long-term ephemeris files for the CloudSat mission to support the crossing analysis

Mission Plan Development

- The FDS team modified an existing mission plan to parse the VCM data
- Initial FreeFlyer mission plan:
 - Parsed VCM (after retrieval of VCM zip file from Space-Track site)
 - Propagated seven days and wrote ephemeris in OEM format
 - Called Matlab to generate A-Train phasing plot
- Expanded propagation to 21 days to support crossing status packages
- Wrote separate script to extract and write VCMs as individual files
- Shifted Consultative Committee for Space Data Systems (CCSDS) Orbit Ephemeris Message (OEM) ephemeris start time to next whole minute to support more consistent Close Approach analysis results in CCS
- Leveraged improved close approach algorithm for refined Time of Closest Approach (TCA) estimate
- More updates described with figures in the next two slides
 - Close approach plot
 - Radial/In-track/Crosstrack (RIC) separations and violation report

Add Close Approach Plot



Add Close Approach Reports

- RIC Separations Report – note: “ZOE” below is “Zone of Exclusion”

FDS TanSat to GCOMW1 Range Report
 Lead Spacecraft Ephemeris Used: TanSat_41898_fromVCM_[YYYYDOYHHMM].oem
 Target Spacecraft Ephemeris Used: SOEMP-4WEEK_GCOMW1_F20170406_000000_T20170504_000000
 Analysis Start Epoch: Apr 14 2017 03:49:00.000
 Analysis End Epoch: May 05 2017 03:50:00.000
 Close Approach Reference Values:
 ZOE Radius: 2 km
 ZOE Along Arc Track Separation: 25 km
 ZOE Cross Track Separation: 25 km
 Close Approach Threshold: 300 km

Reference Spacecraft Epoch	Range (km)	Radial Separation (km)	Along Arc Track Separation (km)	Cross Track Separation (km)
Apr 14 2017 03:49:00.000	3047.19288	13.53971	-3071.89937	119.63293
Apr 14 2017 03:50:00.000	3044.89337	13.58762	-3069.74043	114.46138
Apr 14 2017 03:51:00.000	3042.59997	13.60596	-3067.58913	108.82742
Apr 14 2017 03:52:00.000	3040.32543	13.59414	-3065.45526	102.75404
Apr 14 2017 03:53:00.000	3038.08223	13.55135	-3063.34827	96.26584
Apr 14 2017 03:54:00.000	3035.88248	13.47665	-3061.27713	89.38901
Apr 14 2017 03:55:00.000	3033.73782	13.36904	-3059.25037	82.15125

- Violation Report

FDS TanSat to GCOMW1 Violation Report
 Lead Spacecraft Ephemeris Used: TanSat_41898_fromVCM_[YYYYDOYHHMM].oem
 Target Spacecraft Ephemeris Used: SOEMP-4WEEK_GCOMW1_F20170406_000000_T20170504_000000
 Analysis Start Epoch: Apr 14 2017 03:49:00.000
 Analysis End Epoch: May 05 2017 03:50:00.000
 Close Approach Reference Values:
 ZOE Radius: 2 km
 ZOE Along Arc Track Separation: 25 km
 ZOE Cross Track Separation: 25 km
 Close Approach Threshold: 300 km

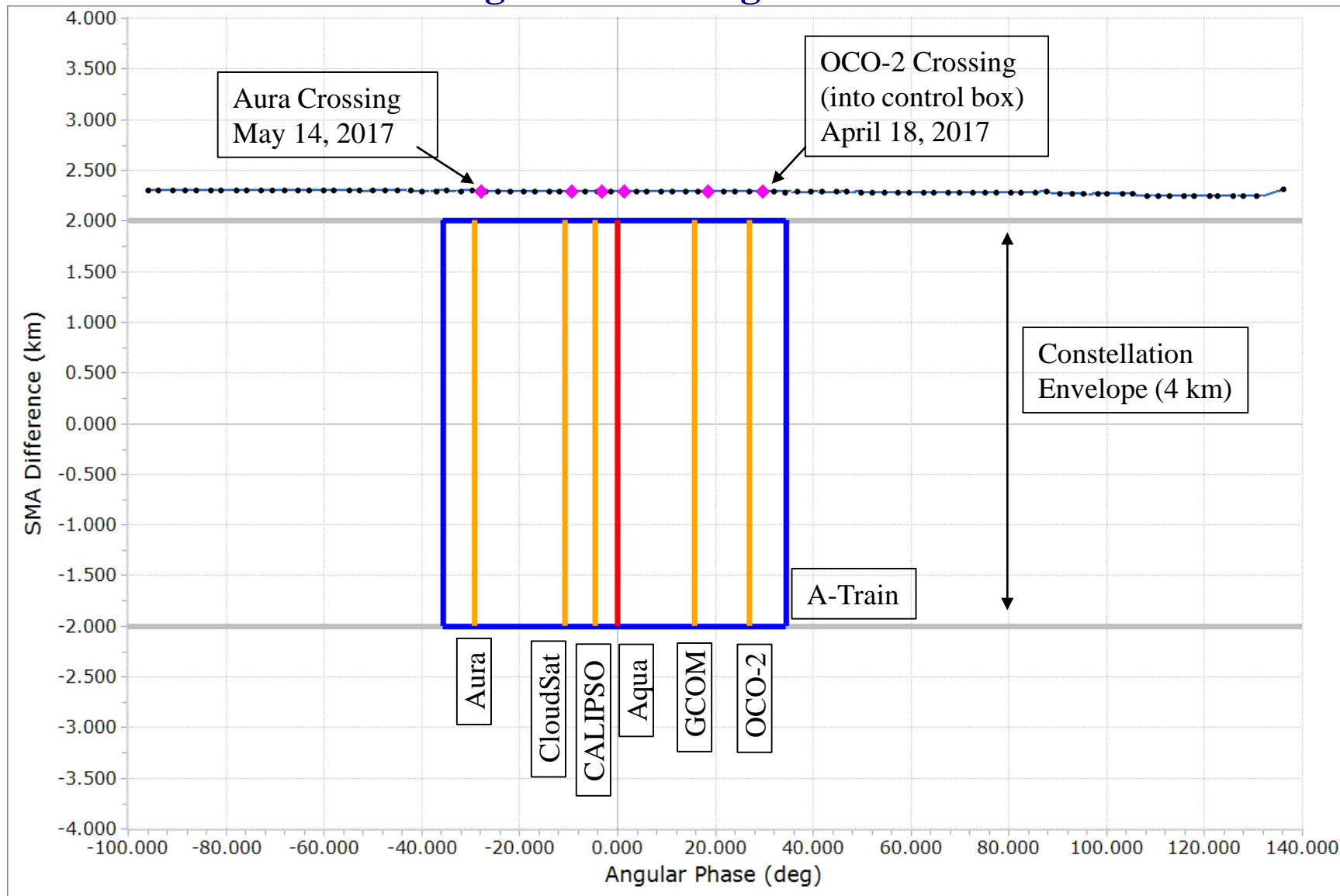
BEGIN DATA	Epoch (UTC)	Range (km)	Radial Separation (km)	Along Arc Track Sep. (km)	Cross Track Sep. (km)	Duration (min)
Type of Violation						
Range ZOE Violation Start:	Apr 22 2017 08:06:00.000	298.33226	12.47186	-294.42921	48.17625	
Cross Track ZOE Violation Start:	Apr 22 2017 08:08:47.000	291.65191	10.52954	-290.62661	24.96252	
Cross Track ZOE Violation End:	Apr 22 2017 08:14:35.000	286.34292	5.74731	-285.32297	-25.04292	5.800
Radial ZOE Violation Start:	Apr 22 2017 08:18:44.000	289.88277	1.99676	-283.84099	-59.14073	
Radial ZOE Violation End:	Apr 22 2017 08:23:11.000	298.62060	-2.00928	-284.37195	-91.10137	4.450
Range ZOE Violation End:	Apr 22 2017 08:23:47.000	300.03457	-2.53147	-284.60341	-94.90670	17.783
Range ZOE Violation Start:	Apr 22 2017 09:38:47.000	296.95749	15.61367	-281.95163	92.82331	

- Most recent additions:
 - Incorporated VCM extraction into main script
 - Add leading zeros when missing from VCM epoch
- Potential forward work:
 - Add Altitude vs. Latitude plots
 - Add North and South Pole separation plots
- Objective is to have all inputs for a crossing analysis package generated by a single offline analysis tool

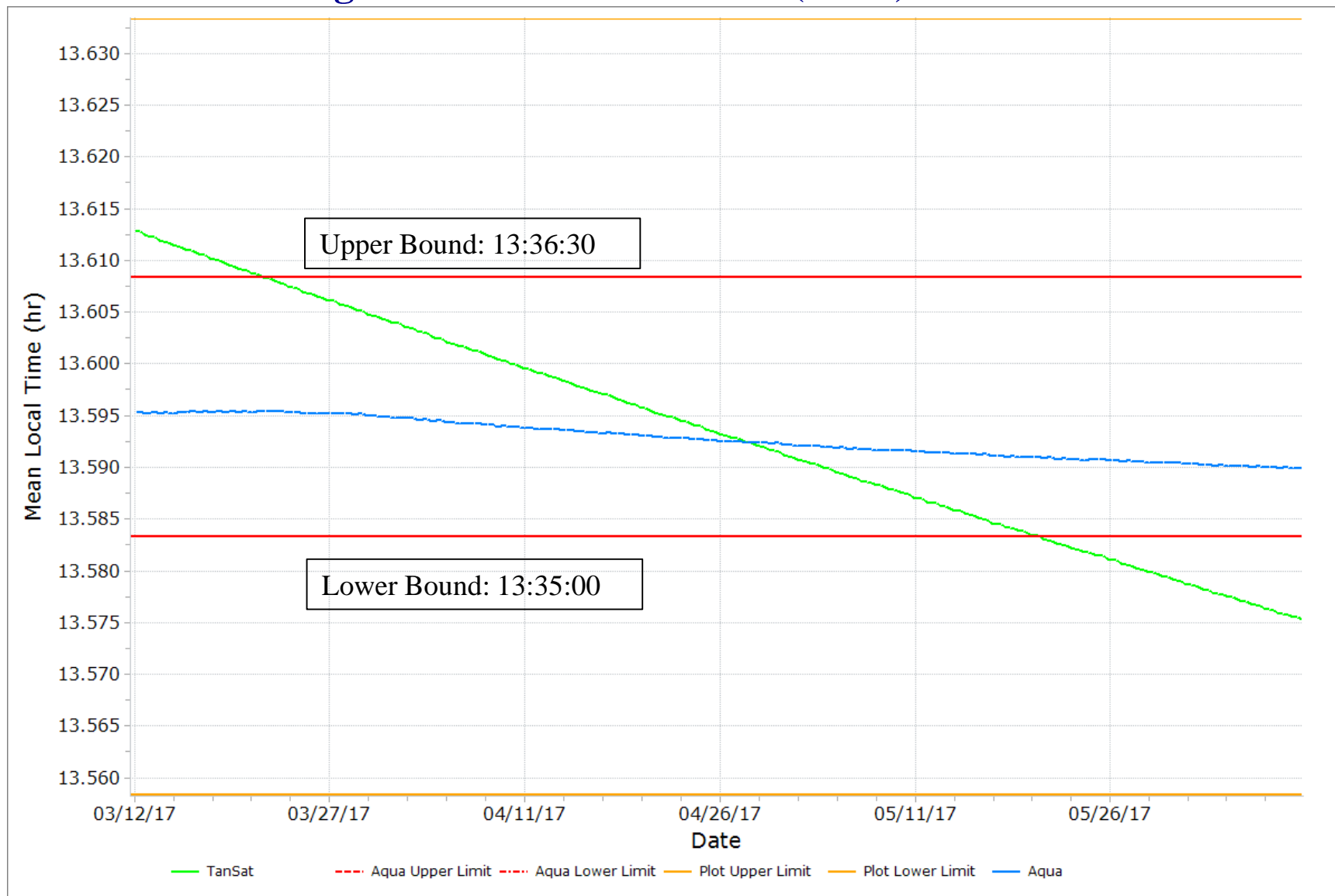
Evolution of Ops Support

- Generated OEMs made available to users on CCS
 - VCM propagated and written to OEM format
 - Product Rule for TanSat mission on Test CCS (added later to Earth Observing Center [EOC] CCS)
 - Ephemeris lengthened from 7 to 21 days
- Determining and reporting Maneuvers
 - Refinement of criteria for detecting a potential maneuver
 - QA of ephemeris comparison results
 - Established the reporting chain (maneuver to be confirmed by Joint Space Operations Center [JSpOC])
- Operational support
 - Added weekend support
 - Provided B-1 week notification of EOS maneuvers to Mission Operations Working Group (MOWG) teams
- Crossing status packages due two weeks from crossing date
- Special Analyses
 - Extra long duration (e.g., spanning Afternoon Constellation – [also known as the “A-Train”])
 - “What If” Constellation insertion scenario

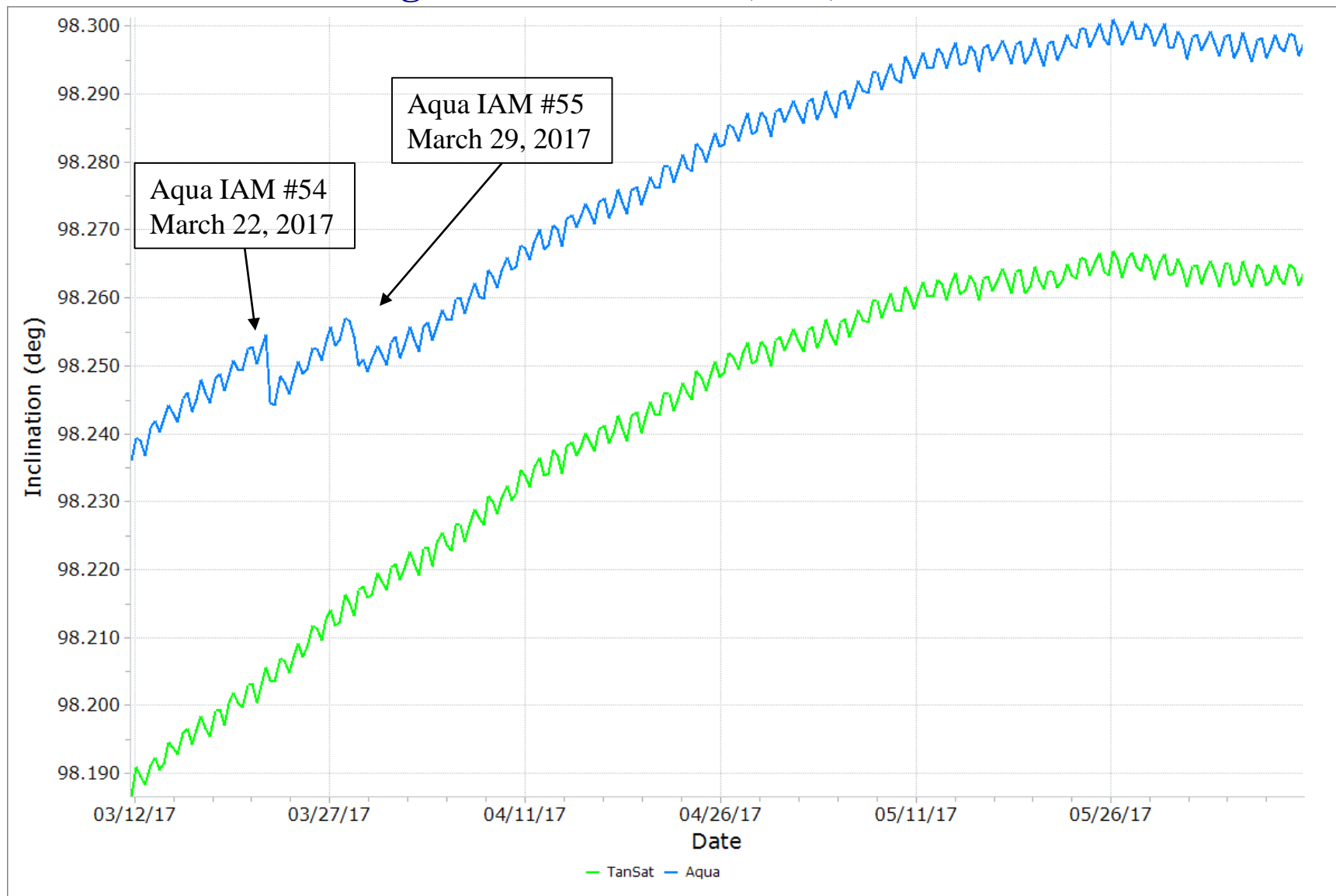
Long Term Phasing – A-Train



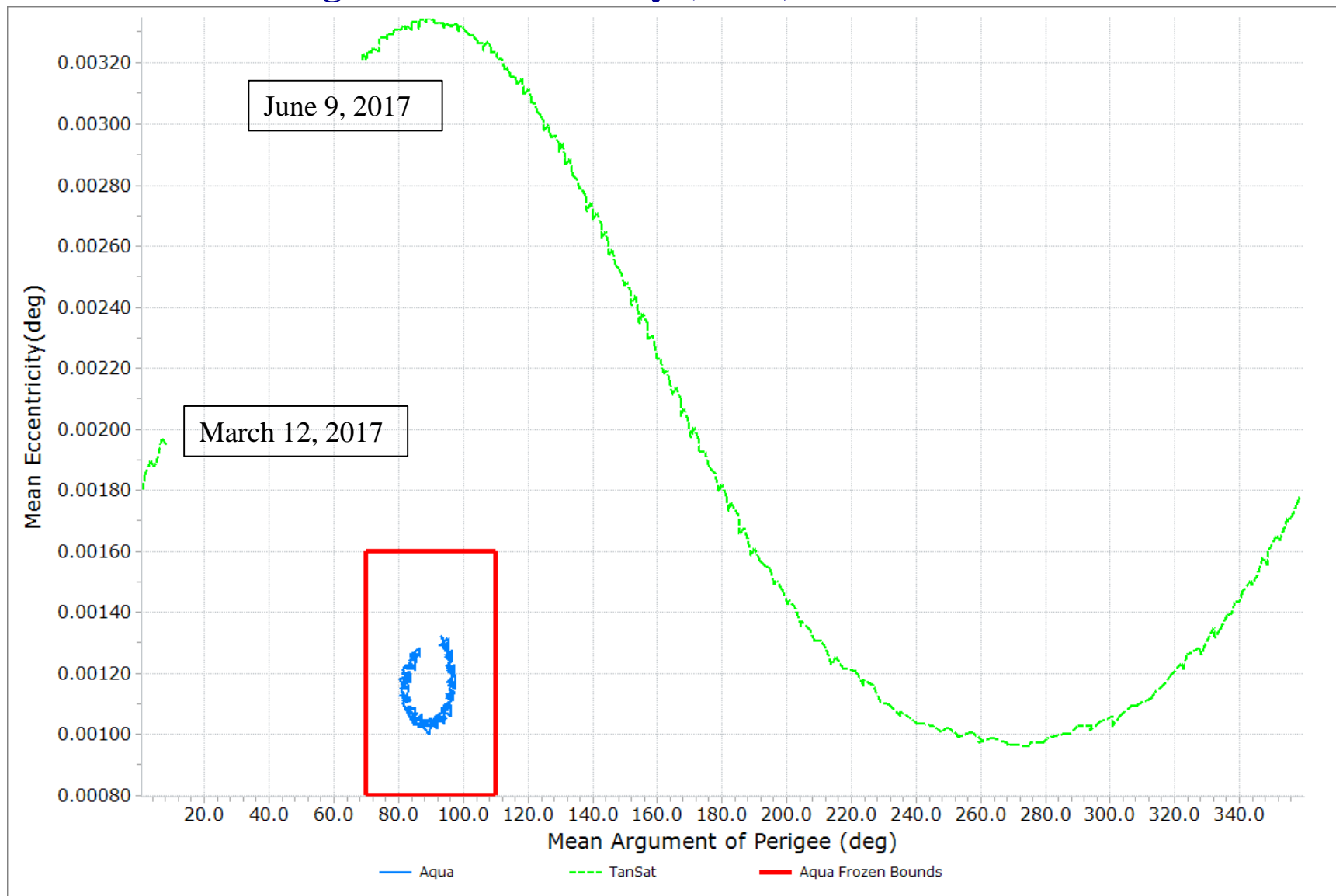
Long Term Mean Local Time (MLT) Evolution



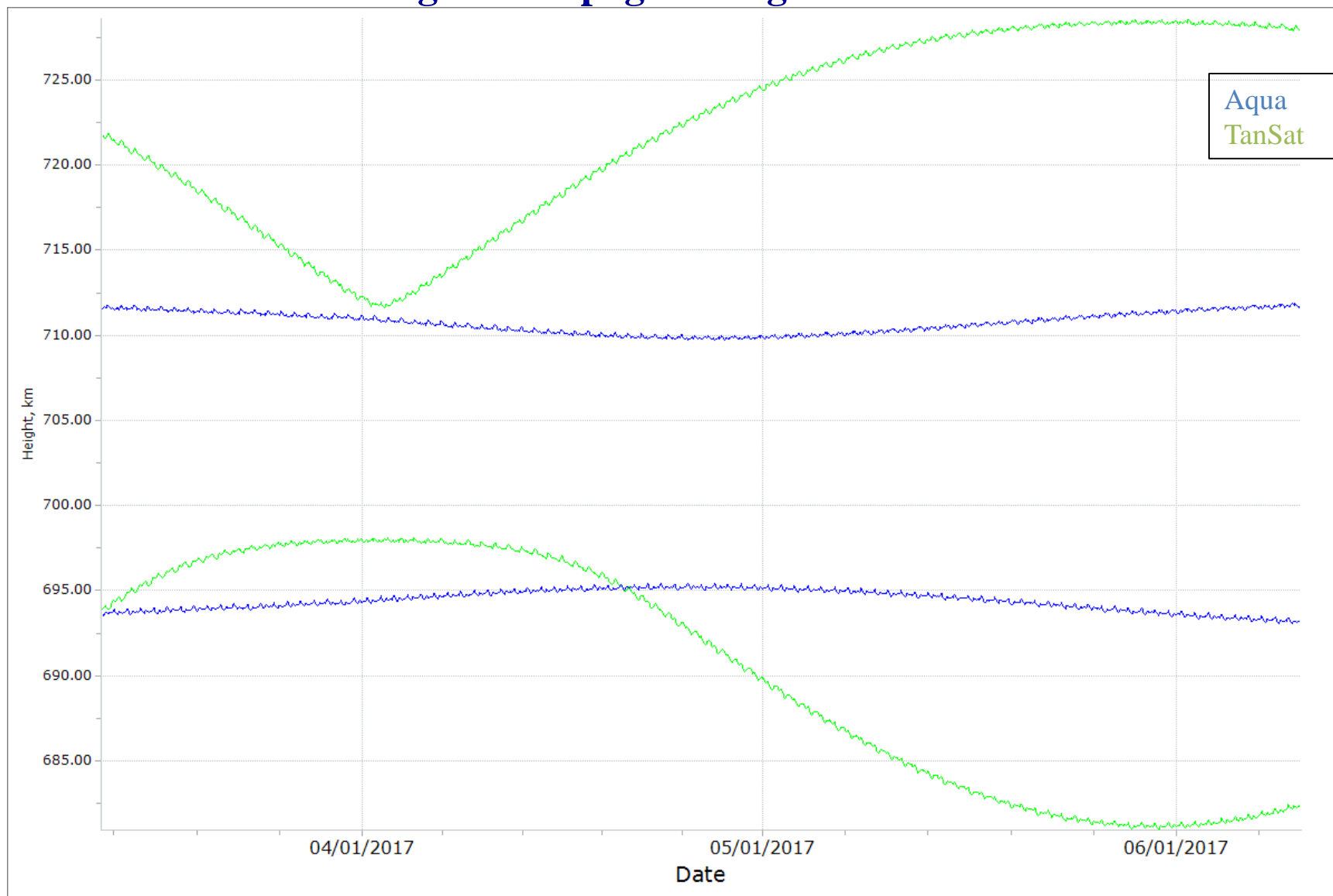
Long Term Inclination (INC) Evolution



Long Term Eccentricity (ECC) Vector Evolution



Long Term Apogee/Perigee Evolution



Hypothetical TanSat Insertion Assumptions

- TanSat to enter the Constellation between OCO-2 and GCOM-W1
- The target orbit must meet the Constellation orbit definition
- Sun-synchronous frozen orbit with a 16-day/233 revolution repeat with the following elements:
 - Mean semi-major axis: 7077.732 km
 - Mean eccentricity: 0.00118
 - Mean inclination: 98.20 degrees (Sun-synchronous)
 - Mean argument of perigee: 90.0 degrees
- The same World Reference System-2 (WRS-2) path flown by Aqua is targeted
- The burns are tightly grouped for a direct descent into the Constellation once the proper phasing is obtained relative to OCO-2 and GCOM-W1

Hypothetical TanSat Insertion Results

- “What If” Maneuver Plan to Enter A-Train
 - One inclination and four altitude burns
 - Large burns required to achieve proper frozen orbit targets

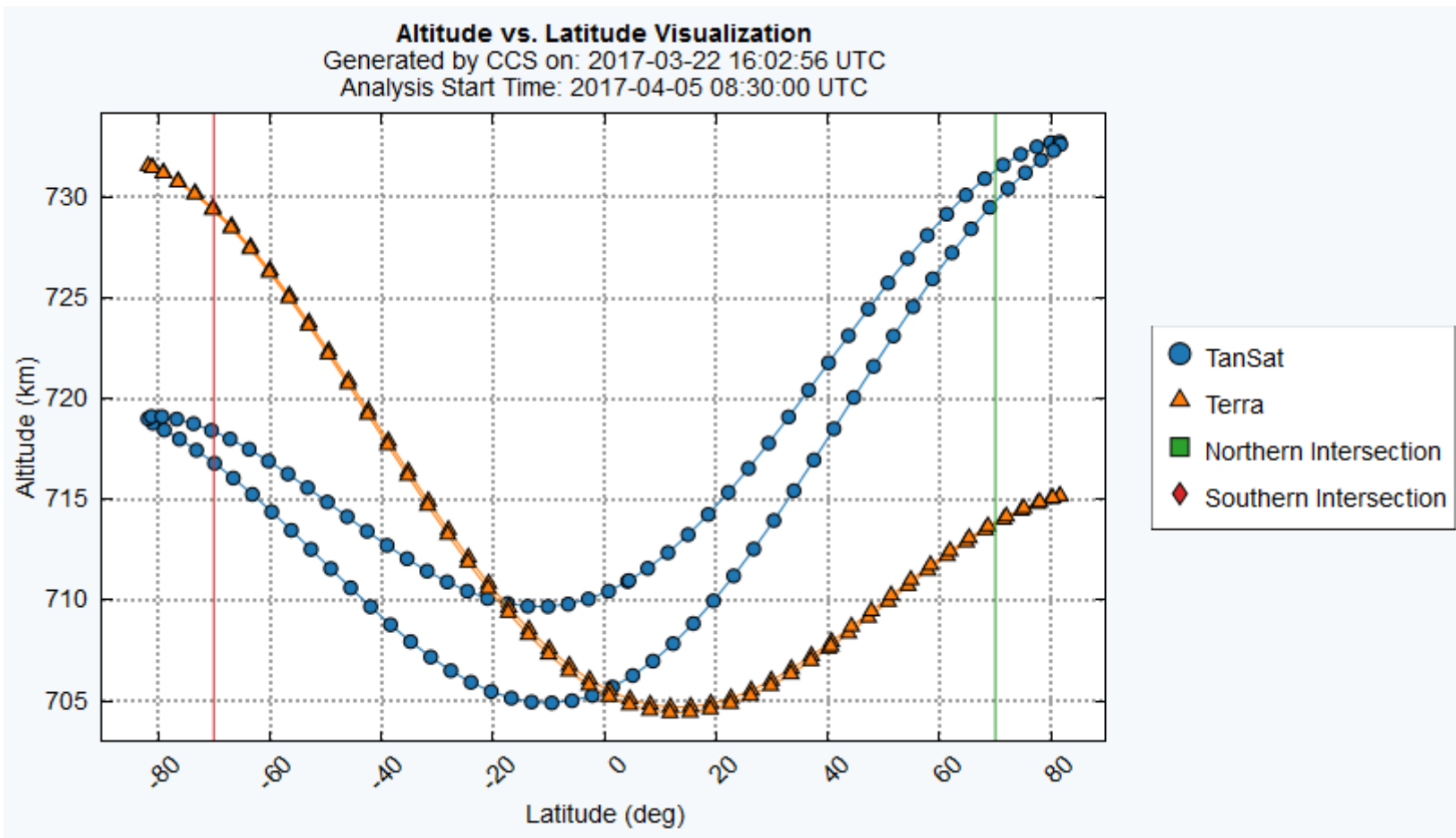
Maneuver #	Maneuver Type	Date	Delta-Velocity (Delta-V) (m/s)	Semi-Major Axis (SMA) Difference (km)	Apogee Altitude* (km)	Perigee Altitude* (km)	Mean Eccentricity*	Mean Argument of Perigee (AoP)*
1	Inclination Maneuver	4/30/2017	-4.5	-0.03 ($\Delta i = 0.034^\circ$)	724.30	690.00	0.002333	153.84
2	Frozen Orbit	4/30/2017	-5.0	-9.48	705.76	687.68	0.001289	129.99
3	Frozen Orbit	5/3/2017	3.0	5.57	706.50	686.75	0.000740	97.42
4	Frozen Orbit	5/3/2017	-1.1	-2.06	705.80	692.00	0.000962	85.47
5	Frozen Orbit	5/3/2017	1.85	0.09	706.00	691.98	0.000973	85.12

*Post maneuver.

Crossing Analysis Package

- Generated two weeks before crossing
- Afternoon Constellation Crossings
 - Typically two members included per package
 - Separation numbers on range, along-track, cross-track, and radial
 - Along-track phasing plot
 - Close approach plot
 - Altitude vs. Latitude single orbit plot
- Morning Constellation crossings
 - Terra, LandSat-7 (L7), and LandSat-8 (L8)
 - Earth Observer-1 (EO-1) no longer considered
 - Separation numbers at both North and South Pole
 - Phasing at the Poles plot
 - Close approach plot for both North and South Pole
 - Altitude vs. Latitude single orbit plot

Sample Altitude vs. Latitude Single Orbit Plot

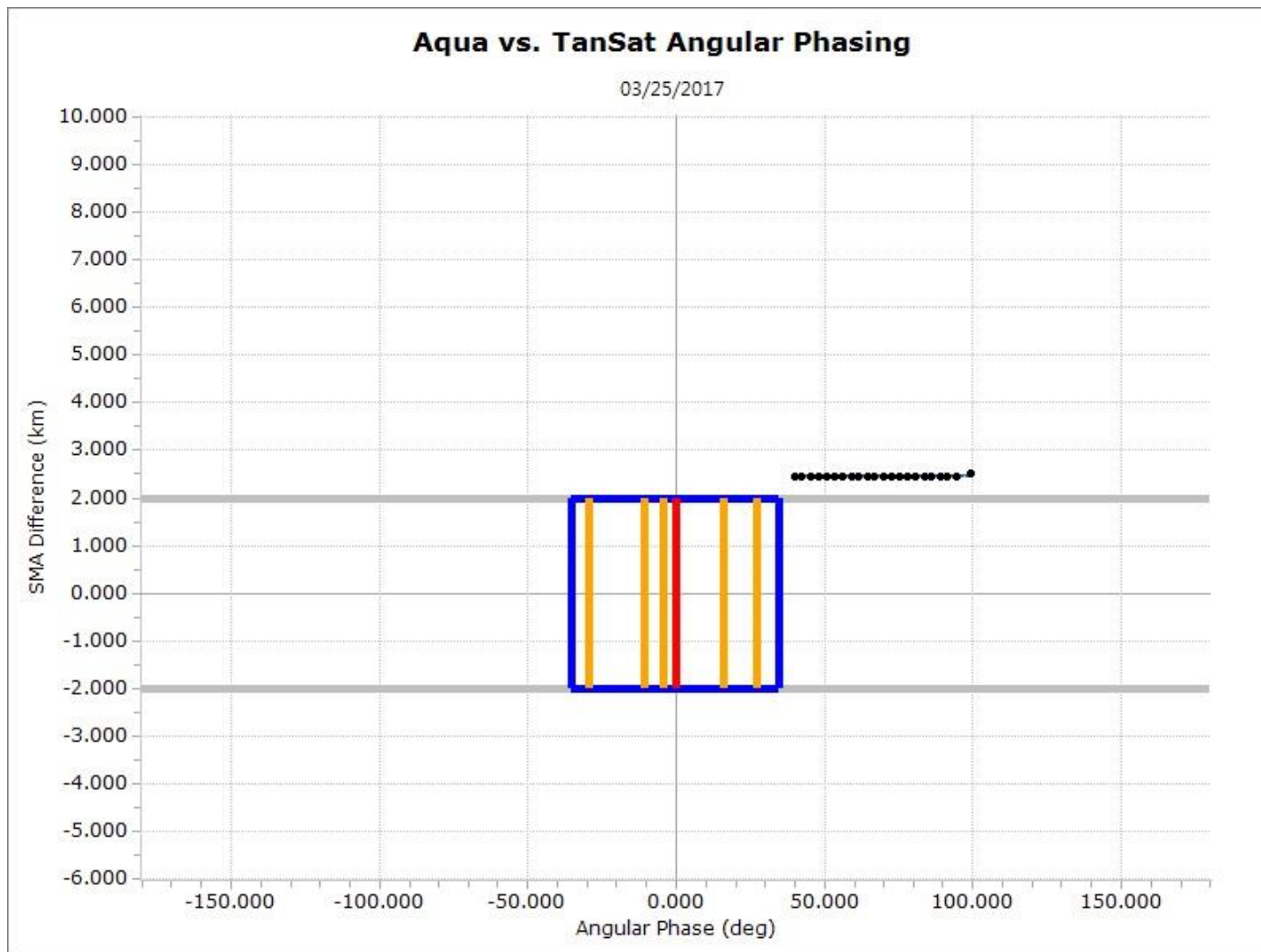


- FDS team continues to monitor the TanSat orbit daily (including weekends)
- No maneuvers have yet been detected
- JSpOC support to confirm any suspected maneuvers
- TanSat has phased behind the A-Train for the second time with a synodic period of approximately 142 days
- The last crossing of a control box phasing limit was Landsat-8 on May 22nd
- Subsequent crossings:
 - Landsat-7 on July 28th and Terra on August 10th
 - OCO-2 on August 25th and GCOM-W1 on August 29th
 - Aqua on September 4th and CALIPSO on September 6th
 - CloudSat on September 8th
 - Aura on September 19th

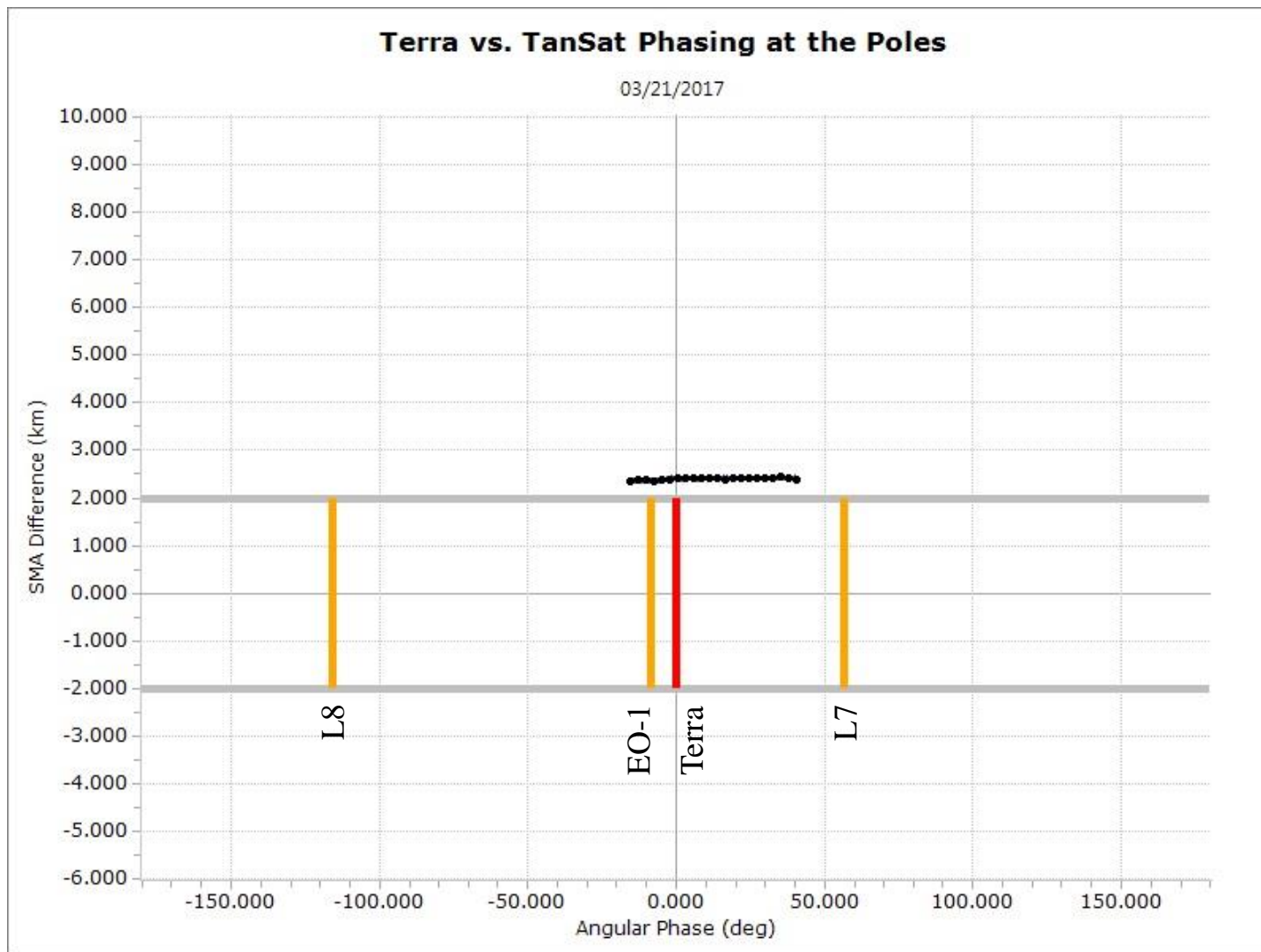
Backup Slides

Afternoon Constellation Phasing Plot
Morning Constellation Phasing Plot
SMA Difference with Prior Ephemeris
INC Difference with Prior Ephemeris
Phasing During Hypothetical Insertion
ECC Vector During Hypothetical Insertion
MLT During Hypothetical Insertion

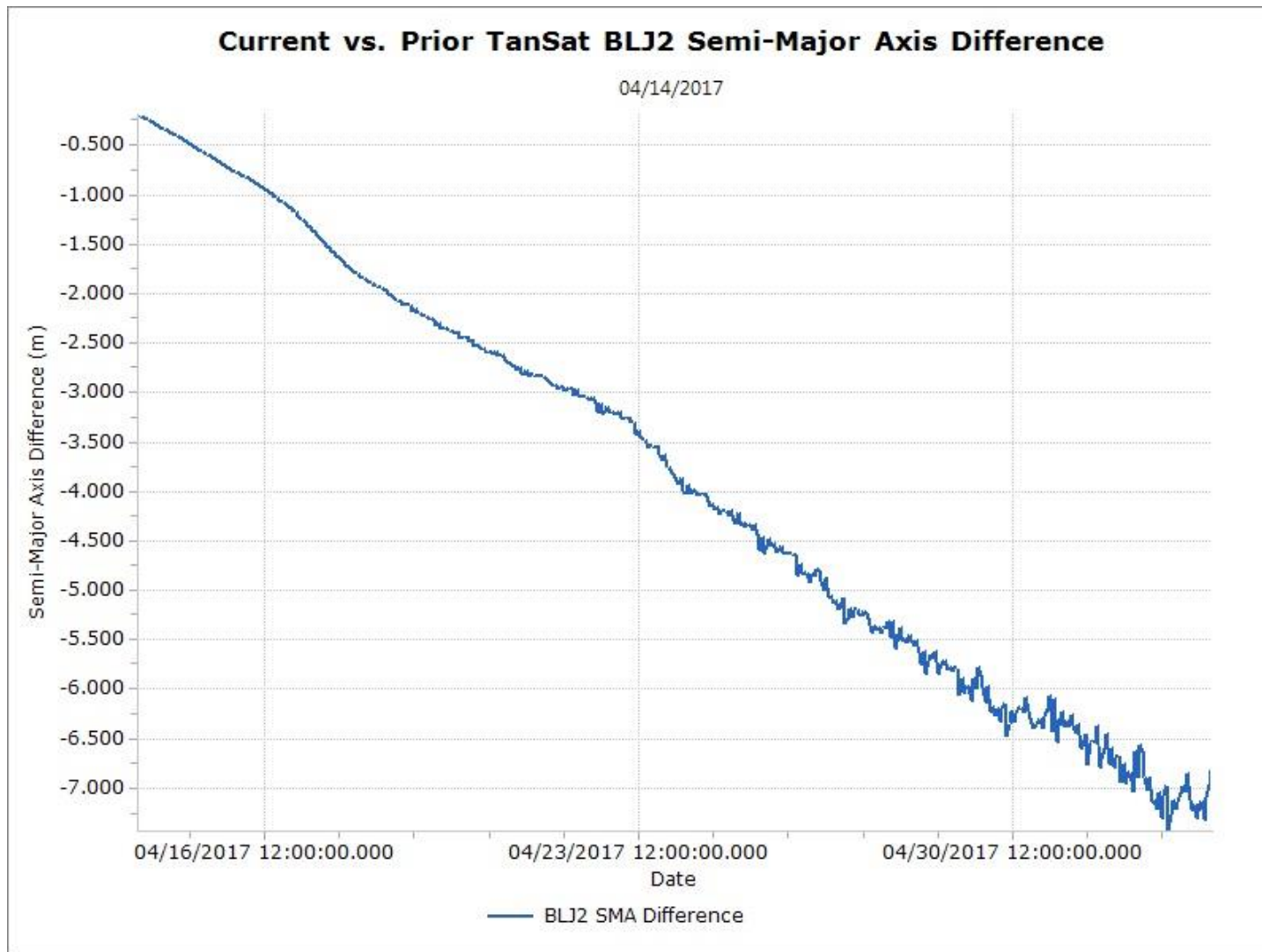
Plot Afternoon Constellation in FreeFlyer



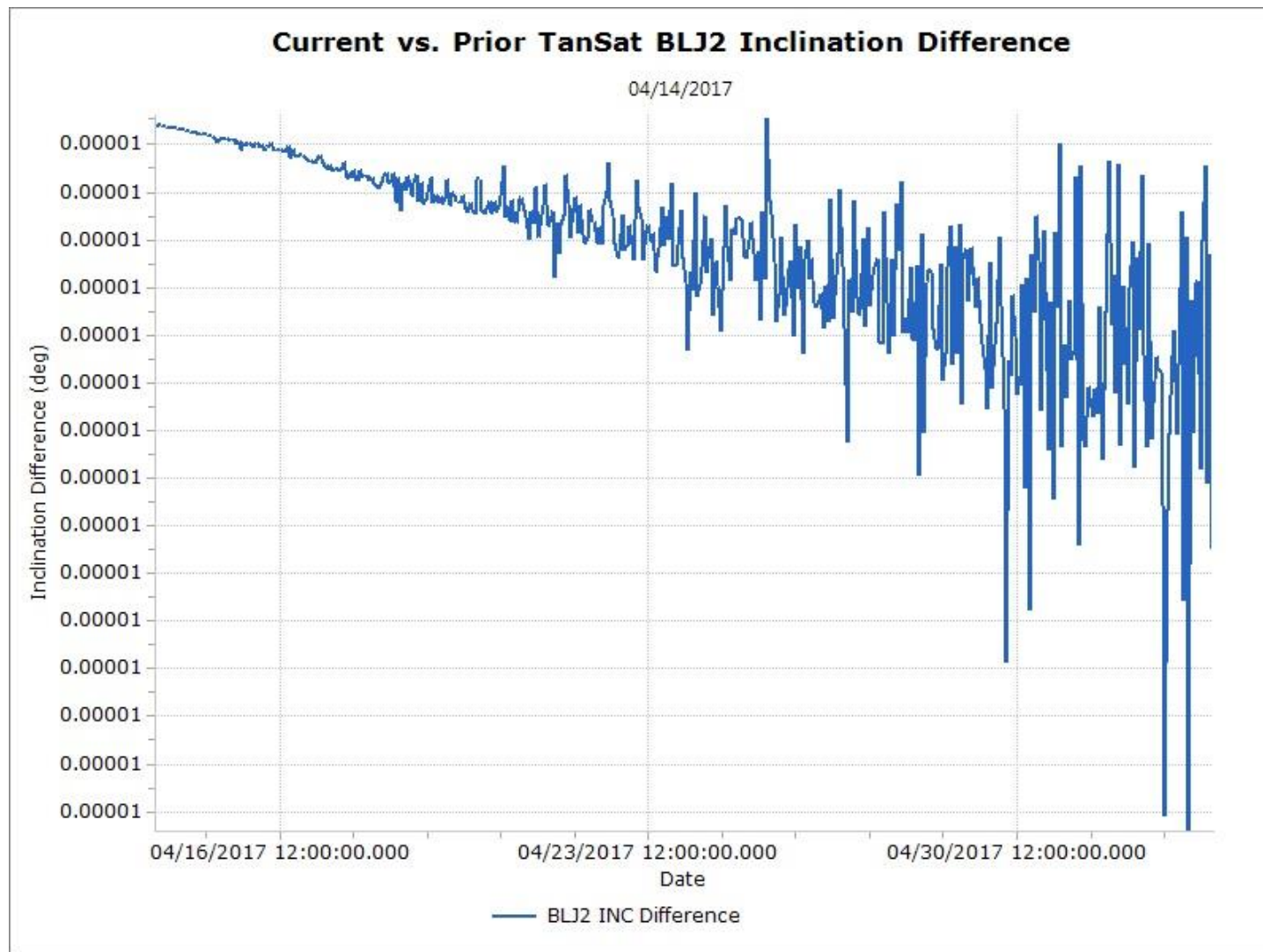
Plot Phasing with Morning Constellation



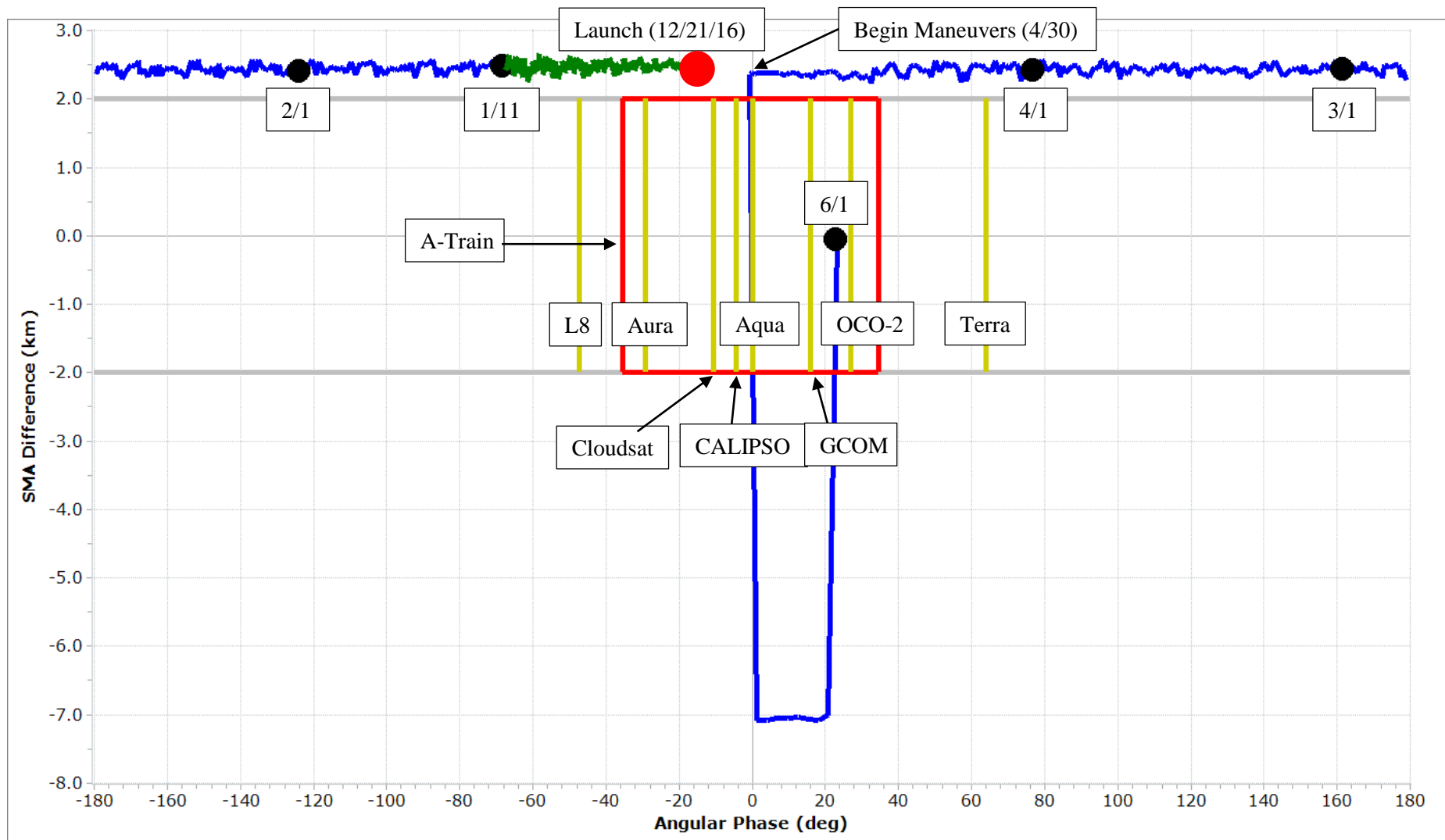
SMA Difference with Prior Ephemeris using Brouwer-Lyddane (J2) elements (BLJ2)



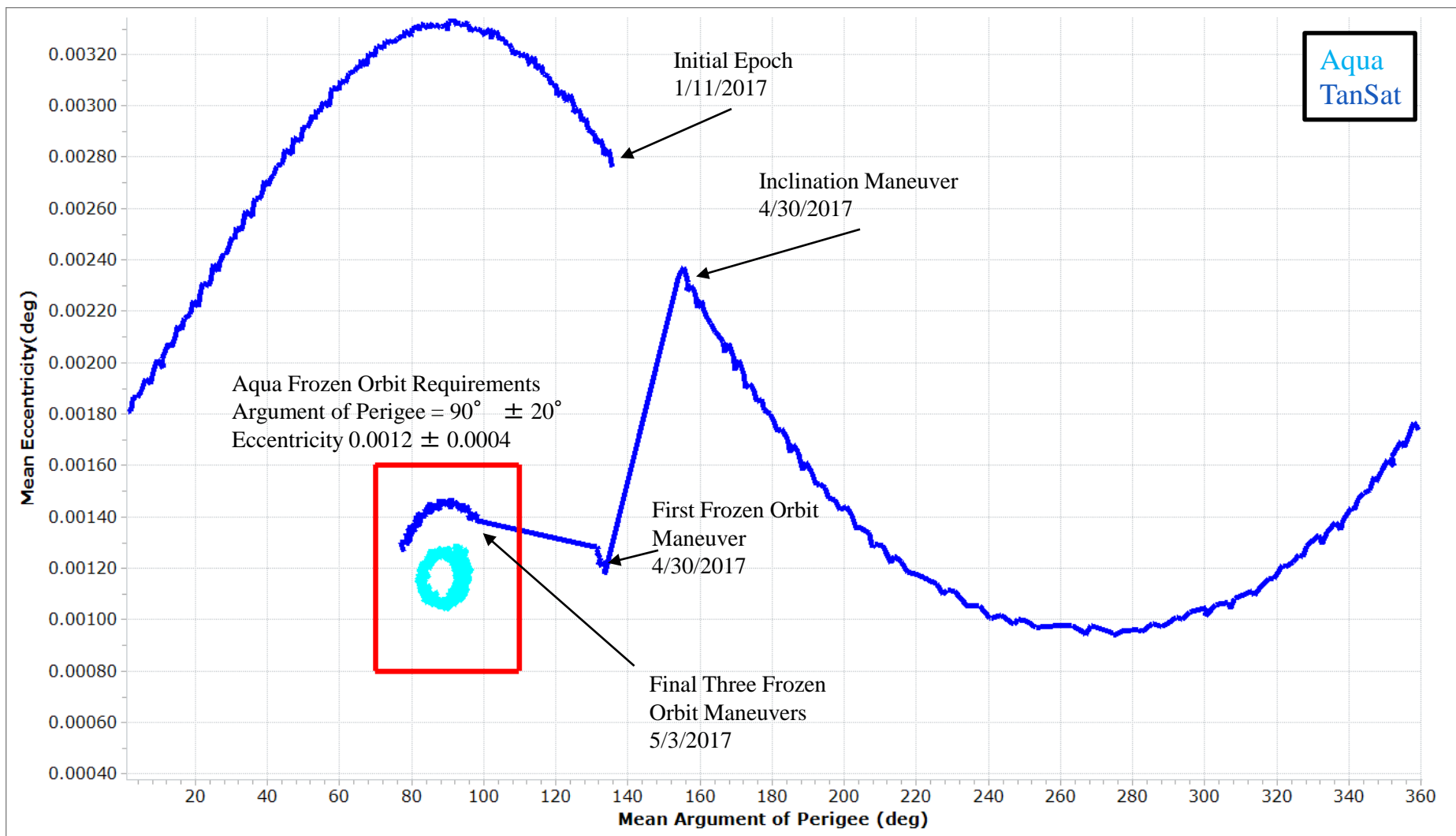
INC Difference with Prior Ephemeris



Phasing During Hypothetical Insertion



ECC Vector During Hypothetical Insertion



MLT During Hypothetical Insertion

